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Water Quality in Agricultural Watersheds
Impact of Riparian Vegetation during Base Flow

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WATER QUALITY IN AGRICULTURAL WATERSHEDS: IMPACT OF RIPARIAN VEGETATION DURING BASE FLOW¹

Isaac J. Schlosser and James R. Karr²

ABSTRACT: Water quality was monitored for 12 months during base flow periods in six agricultural watersheds to evaluate the impact of riparian vegetation on suspended solids and nutrient concentrations. In areas without riparian vegetation, both instream algal production and seasonal low flows appeared to be major determinants of suspended solids, turbidity, and phosphorus concentrations. Peak levels of all parameters were reached during the summer when flows were reduced and benthic algal production was high. Smaller summer peaks were reached in streams receiving major point inputs but peaks occurred downstream from the input. Instream organic production was low in riparian areas. Riparian vegetation was associated with lower instream algal production and lower suspended solids concentrations. Concentrations of suspended solids remained relatively constant, while phosphorus and turbidity increased in association with leaf fall in autumn. Interstream flow conditions in association with the riparian vegetation reduced instream algal production and increased the importance of instream organic production in controlling water quality. These results suggest that riparian vegetation is important in regulating water quality in agricultural watersheds during base flow. Flow should emphasize maintenance of riparian vegetation and stable flow conditions.

KEY TERMS: agricultural watershed; water quality; riparian vegetation; seasonality; base flow; suspended solids; nutrients.

INTRODUCTION

Societal concern for deteriorating water quality has resulted in federal and state initiatives to halt and even reverse that degradation (U.S. Congress, 1972). In agricultural watersheds the strategy for achieving this goal involves identifying critical erosion areas in the terrestrial portion of the watershed and treating these areas with traditional soil conservation practices (Miller, et al., 1979). This approach assumes physical processes in the terrestrial portion of the watershed are the primary determinants of water quality. A number of geomorphological (Leopold, et al., 1964; Evans and Schorpp, 1977; Freely, 1979), hydrological (Staff and Yang, 1972; Yang and Staff, 1974), and ecological (Cummins, et al., 1972; Swanson and Bachmann, 1976; Borusan and Likens, 1979) studies indicate that physical and biological processes in channel and riparian areas also have a substantial impact on water quality. Thus, water resources planning in agricultural watersheds requires a better understanding of how physical and biological processes in terrestrial, riparian, and aquatic portions of watersheds interact to regulate water quality under a range of flow conditions (Karr and Schlosser, 1978).

The impact of riparian vegetation and channel morphology on water quality during elevated flows is examined in another paper (Schlosser and Karr, 1981). The purpose of this paper is to evaluate the impact of riparian vegetation on water quality under base flow conditions. The hypothesis tested is that the presence of riparian vegetation significantly alters the seasonal dynamics of water quality relative to areas without riparian vegetation. The significance of these dynamics for programmatic water quality management in agricultural watersheds is discussed.

STUDY AREAS

Six agricultural watersheds, differing in type of riparian vegetation and magnitude of point source inputs were studied. Five are located in Champaign and Vermilion Counties within 50 km (30 miles) of Champaign-Urbana, Illinois (Figure 1). One is located 100 km (60 miles) south of Champaign-Urbana in Giles and Cumberland Counties (Figure 1). The dominant land use in all watersheds is greater than 80 percent row crop agriculture of predominantly corn and soybeans.

Spoon River (watershed area = 35 km²; 13.5 mi²), Big Ditch (45 km²; 3.7 mi²), and the Embury River (60 km²; 23 mi²) have cultivation to the stream edge and no riparian vegetation. There are no municipal inputs in Spoon River, although small septic inputs have localized impacts on water quality. Municipal waste water inputs of 75 million (70 million gal) and 40,000 liters per day (114,000 gal) enter the upper Big Ditch and Embury River, respectively.

Riparian vegetation varies along Jordan Creek (35 km²; 13.5 mi²). The upper 6.4 km (4 miles) of the stream are channelized with no riparian vegetation. The mainstem below this is bordered by a strip of riparian vegetation 10-400 meters (30-1,300 ft) wide. The vegetation is composed of maple (*Acer* spp.), willow (*Salix* spp.), box elder (*Acer negundo* L.), hackberry (*Celtis occidentalis* L.), ash (*Fraxinus* spp.), black cherry (*Prunus serotina* Ehrh.), oak (*Quercus* spp.), black wood (*Opulus deltoides* Marsh.), sycamore (*Platanus occidentalis* L.), ironwood (*Carpinus caroliniana* Walt.), elm (*Ulmus* spp.), and coage orange (*Maclura pomifera* Raf.)

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(Figure 1). A channelized side branch enters the mainstream (Figure 1) and is culminated to the stream edge (except in bordered areas). This side branch receives a small septic input from Falmouth, Illinois, but has little impact on water quality in the mainstream.

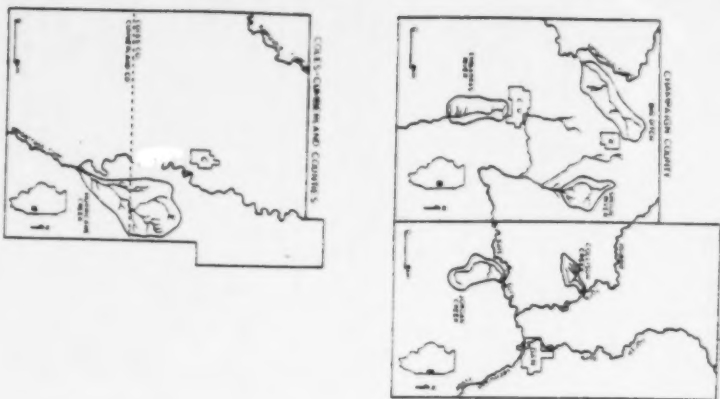


Figure 1 Waterbird locations in (Thamphayn, Vietnam, China, and Northernland Vietnam, Hanoi (4-1) (Thamphayn-Africa, H. Hanoi, Hanoi (Barro), (4-1) (Barro))

Kubota Creek (30 km², 7.7 m³) is bordered by a strip of riparian vegetation 10–75 meters (to 2.5 ft) wide comprised of oak, maple, orange, orange, two elms, black cherry, ash, hackberry, and blue grass (*Poa*) pasture. It is intermittent during

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wood, willow, and sycamore with scattered individuals of maple, elm, and ash. Few oaks occur along the stream. There are no municipal inputs but feedlots have localized impacts on water quality.

METHODS

SURVEYS were conducted in each watershed to identify past trends of riparian conditions and point inputs. Fifty-four water sampling stations were located in the six watersheds (7.12 per watershed). Stations were located in both headwater and downstream areas and above and below major point inputs. Locations of stations in each watershed is provided in Schloesser and Karr (1980).

Water was defined as those periods when surface runoff had not occurred for at least one week. Six watersheds were sampled at monthly intervals from November 1977 through April 1979, when conditions permitted. Samples were collected by attaching a one-liter bottle to a metal pole and lowering it at a uniform rate to the bottom of the water column. The bottle was reversed upon contact with the bottom and raised to the surface at a uniform rate. This technique followed standard United States Geological Survey procedures for sampling throughout the water column (Evan and Chappelear, 1977).

Sampling was placed in an ice chest and then frozen within 24 hours of collection. All chemical analyses were conducted by the Water Quality Laboratory, Illinois Natural History Survey. Suspended solids were measured by filtering the sample with a Gelman type A glass fiber filter and drying at 100°C. Turbidity was measured with a Mott Mac Model 150 turbidimeter. Soluble orthophosphate was measured on the filtrate using the ascorbic acid method. Total phosphorus was measured with the ascorbic acid method after digestion of the total sample. Particulate phosphorus was based on the difference between total phosphorus and soluble orthophosphate and included both organic and inorganic forms. All of these methods followed established procedures (American Public Health Association, 1976; U.S. Environmental Protection Agency, 1974).

RESULTS

Definition of Seasons

The sampling was designed to evaluate the impact of the seasonal changes in the hydrology of the river on periphyton vegetation on seasonal dynamics of water quality. Three stations were established based on periodicity of biotic activity and flow conditions. Sampling in winter (December–February) was limited by ice cover. Because of similarity in water quality between winter and spring (March–April and May), samples were combined into one winter (throughout and May). This represents a period of regular flow spring (085) period.

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and decreased primary production. Mid May through August was defined as summer (S), a period of moderate to low flow conditions and, at areas without riparian vegetation, intense primary production. During the fall (F) (September through November) primary production declined as water temperatures decreased. Flow rates were low and areas with riparian vegetation experienced inputs of leaves.

Freezing of Data

An statistical analysis involved *t*-test comparisons of means of independent samples with a two-tailed hypothesis. Tests were based on separate rather than pooled variance estimates for populations with unequal variances.

excessive pointy by season and station for each sampling site. Pooling across years was necessary for the WS period because of the very few samples collected at the WS samples from both 1978 and 1979. The significant differences ($P < 0.10$) were detected for all water quality parameters between years. The possibility of pooling stations within watersheds was also examined. Comparison within a stream of stations with similar riparian conditions and no point inputs indicated no significant difference ($P > 0.05$) in all parameters over all seasons. A comparison between upper Jordan Creek and Spring Run, both areas without riparian vegetation, yielded no significant difference ($P > 0.10$) across all seasons and parameters. Samples from areas with no riparian vegetation or nonpoint inputs were therefore pooled both within and between streams for analysis of seasonal trends. Significant ($P < 0.10$) differences among stations occurred within the Dutch and the Finkenau River because of nonpoint inputs. Analyses in these streams emphasized seasonal changes in the gradient of water quality downstream from the input.

Streams Without Point Inputs

The effect of riparian vegetation was similar in areas without riparian vegetation with stream in areas without riparian vegetation. Superimposed with the same concentrations were similar among streams during WS (Figure 3). During S, riparian vegetation significantly ($P<0.01$) (Figure 2A) in streams without riparian vegetation, but did not change (Figure 2B, 3) throughout the year in areas with permanent flows and riparian vegetation. Streams with riparian vegetation and intermittent flow also presented significant ($P<0.01$, Figure 2B) increases in α -pinene levels during S. However, a significant ($P<0.01$) decrease occurred in β -

Immunities prevented sample analysis to evaluate the relative contributions of organic and inorganic fractions to suspended solids. Earlier studies suggest benthic algal production was the primary source of elevated suspended solids during summer when the flows occurred and other riparian vegetation had been removed (Swenson and Bachmann, 1970; Aikins, *et al.*, 1975). A decrease in flow was the major factor limiting algal densities. Concentrations of suspended sediment (mg/l) increased from less than $10\text{ }mg/l$ ($0.0009\text{ }g/m^3$) to $140\text{ }mg/l$ ($0.14\text{ }g/m^3$) to greater than $200\text{ }mg/l$ ($0.2009\text{ }g/m^3$) in the South River, near the flows decreased from $10\text{ }m^3/s$ ($1.57\text{ }m^3/s$) to $1\text{ }m^3/s$ to $1\text{ }m^3/s$ ($0.5\text{ }m^3/s$). Other physical parameters

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primary associated with increasing algal concentrations to clouded temperature (Kolton, *et al.*, 1975), Inhof (Ottino, 1956), and upstream bottom area (Sawyer, *et al.*, 1973).

In the present study, seasonal fluctuations in zooplankton with concentrations observed during base flows appear to be due to interactions between stream benthic algal production and transport and distribution of this material. The timing of summer production and increase in vegetated solids was not as extreme where riparian vegetation was present to reduce temperatures and light intensities (Karr and Vannote 1975, Gerbiak and Matlack 1978) and where flow was mainly limited to dilute the algal densities (Swenson and Bachmann 1977b).

Turbidity Turbidity is a function of how much light is scattered by the suspended solids. It is an important water quality parameter because of its impact on the aesthetic quality of water and biological processes such as photosynthesis and predation which are dependent on light intensity. Data from this study and Schloesser and Kerr (1971) indicate significant vegetation and channel morphology have significant impacts on the relationship between turbidity and suspended solids.

periodic treatments to inhibit overgrazing to such periods, such as except in F (Figure 3). Significant ($P < 0.01$) increases in both parameters occurred in 5 m steers and were due to open vegetation (Figure 3A) or with intermediate flow (Figure 3B). Increases in turbidity in the absence of an overgrazing suspended solids threat occurred during F in Jordan and (Cotton Creek) (Figures 3B and 3C), apparently due to leaching of organic from land inputs (Cottons, *et al.* 1972; J. J. Schaefer, pers. obs.). The significant ($P < 0.05$) increase in turbidity occurred in F in Thurston (York, ap. pers.) but the magnitude of increase is influenced by species composition of the riparian vegetation.

also illustrated the importance of in-stream processes than vegetation (Fig. 4). Similar levels of total, particulate, and soluble phosphorus occurred in all streams in WS (Fig. 4). In 3, significant ($P < 0.01$) increases in phosphorus, especially the particulate fraction, occurred in streams without riparian vegetation (Figure 4A). A nearly significant ($P < 0.1$) decrease in total phosphorus occurred in F (Figure 4A). Where flow in intermittent and riparian vegetation is present (Figure 4B), total and particulate phosphorus increased significantly ($P < 0.01$) during S and remained high throughout F. Flooding streams benefited by riparian vegetation (Figures 4B, C) experienced significant ($P < 0.05$) increases in total and particulate phosphorus in F due to leaf inputs.

This seasonal dynamics of phytoplankton concentrations were to be due to sources of particulate phosphorus (Figure 3). Peak phosphorus levels in streams without riparian vegetation occurred during S periods of decreased wastewater sludge production. Peak phosphorus levels in streams with riparian vegetation and continuous flow occurred during periods of low flow and leaf inputs in F. Streams with riparian vegetation and intermittent flow had elevated phosphorus levels during both S and F.

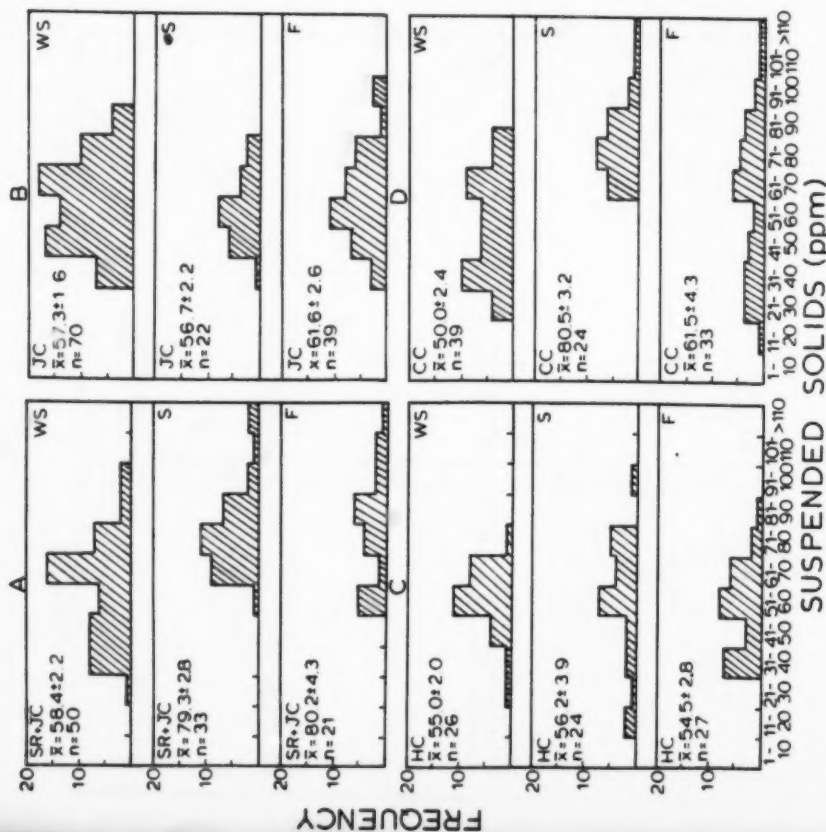


Figure 2. Frequency Distribution of Suspended Solids ($\bar{X} \pm 1 \text{ SE}$) Concentrations in Four Streams. A - Spoon River and Jordan Creek (SR + JC). Regions with no riparian vegetation. B - Jordan Creek (JC). Regions with riparian vegetation. C - Hurricane Creek (HC). D - Cotton Creek (CC). Seasons: WS - Winter-Spring; S - Summer; F - Fall.

Streams With Point Inputs and No Riparian Vegetation

The impact of point inputs was illustrated by the Big Ditch and Embarras River. These streams received an average point discharge of 75 million (20 million gpd) and 430,000 liters (114,000 gpd), respectively, of municipal waste water. All waste waters received secondary treatment.

Suspended Solids

Big Ditch and Embarras River varied according to season and distance from the point source site (Figure 5). WS levels were relatively constant with increases in downstream stations where discharge and velocity were greater. WS and S concentrations of suspended solids were similar in upper and lower reaches.

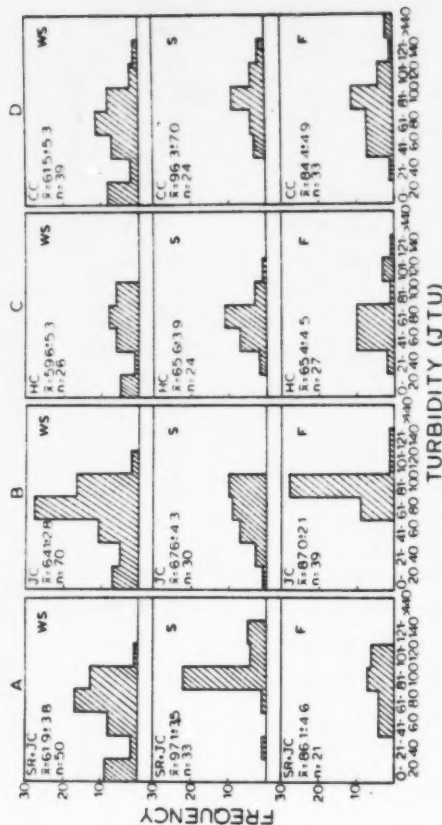


Figure 3. Frequency Distribution of Turbidity ($\bar{X} \pm 1 \text{ SE}$) in Four Streams. A - Spoon River and Jordan Creek (SR + JC). Regions with no riparian vegetation. B - Jordan Creek (JC). Regions with riparian vegetation. C - Hurricane Creek (HC). D - Cotton Creek (CC). Seasons: WS - Winter-Spring; S - Summer; F - Fall.

S suspended solids levels were depressed near the point input but gradually increased downstream. The mid watershed peak was probably due to increased algal production as documented for municipal waste water inputs (Blutcher, 1947). Algal production below point inputs increased gradually and then suddenly, reaching a maximum 8.1 km (5.8 miles) downstream (Blutcher, 1947). The downstream peak was due to toxic effects (perhaps chlorine) below the input, followed by utilization of nutrients until nutrient depletion occurred. The pattern observed for suspended solids suggests material in the water column also follows this pattern.

Low and relatively constant levels of suspended solids occurred below the point input during F (Figure 3). Big Ditch maintained flow in the Embarras River the municipal input depressed levels of suspended solids. Low levels were due to lower algal production in F and flow being maintained by municipal inputs which had low (10-30 ppm) levels of suspended solids.

Turbidity. Turbidity in streams receiving a point input was highly variable. Turbidity was low below sites of point inputs, with gradual increases downstream. The increases were greatest during S periods of higher algal production and least during F periods of decreased production.

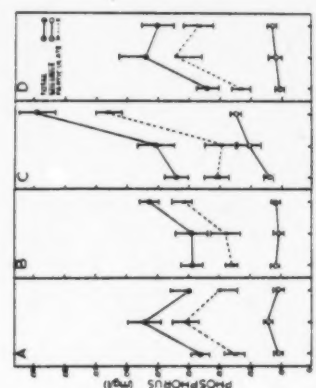


Figure 4. Seasonal Dynamics of Phosphorus Concentrations ($\bar{X} \pm 1 \text{ SE}$) in Four Streams. A - Spoon River and Jordan Creek (SR + JC). Regions with no riparian vegetation. B - Jordan Creek (JC). Regions with riparian vegetation. C - Hurricane Creek (HC). D - Cotton Creek (CC). Seasons: WS - Winter-Spring; S - Summer; F - Fall.

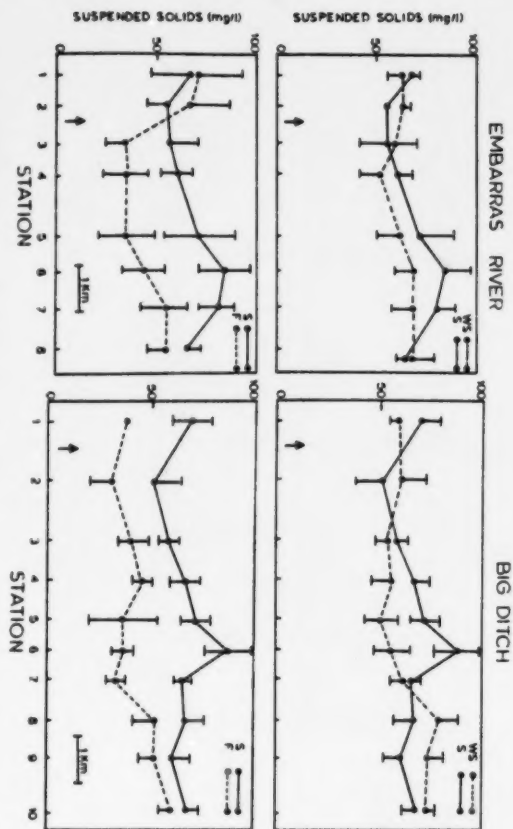


Figure 5. Seasonal Variation in Suspended Solids Concentrations (X ± 1 S.E.) in Big Ditch and the Embarras River. WS - Winter-Spring; S - Summer; 1 - Fall. Position along abscissa proportional to distance from Station 1. Arrow indicates location of point input.

Phosphorus. The point inputs increased both particulate and soluble phosphorus (Figure 6). Both forms decreased below the input during WS but the soluble form persisted at higher concentrations than particulate until each form reached low concentrations. Both forms occurred at higher concentrations below the input in S due to lower flows. Soluble phosphorus decreased rapidly while particulate remained at higher concentrations. This correlated with the previously discussed increase in algal production and suspended solids in downstream stations (Figure 5) during S. High concentrations of both phosphorus components occurred below the point inputs in F due to low flows (Figure 6). However, soluble phosphorus persisted as the dominant form at downstream stations. Particulate phosphorus rapidly decreased to a constant level.

In watersheds with major point source inputs and no riparian vegetation, seasonal dynamics of suspended solids, turbidity and phosphorus also appeared to be controlled by interactions between flow regime and primary production. Increased algal production downstream from the point input in S resulted in increased levels of suspended solids, turbidity, and particulate phosphorus, but depressed soluble phosphorus levels. Low levels of suspended solids but high levels of soluble phosphorus occurred below the point input in F due to low flows and decreased primary production.

DISCUSSION

Organic inputs occur as leaf fall during autumn when riparian vegetation is present (Cummins, 1974). When it has been removed, organic inputs occur primarily during summer as increased benthic algal production (Cedeno and Matzall, 1978). Such shifts in organic inputs, in conjunction with changes in flow regime, regulate the seasonal dynamics of suspended solids, turbidity and phosphorus.

Models for predicting levels of suspended solids over a range of flow conditions are based on the hydrological theory that concentrations of suspended solids are positively correlated with the potential energy of the stream (Yang and Stall, 1973; Stall and Yang, 1972). Potential energy is primarily a function of velocity of the water and slope of the streambed. Our results suggest the theory does not successfully predict seasonal dynamics of suspended solids and related pollutants during base flow conditions. The greatest variation between model predictions and reality occurs when riparian vegetation has been removed and instream organic production is high. Organic matter in suspension does not follow the same physical principles as do inorganic materials (such as sediment) on which most hydrological theory is based (Stall, et al., 1973). Efforts to model water quality during base flows in agricultural watersheds should combine the theory of inorganic material

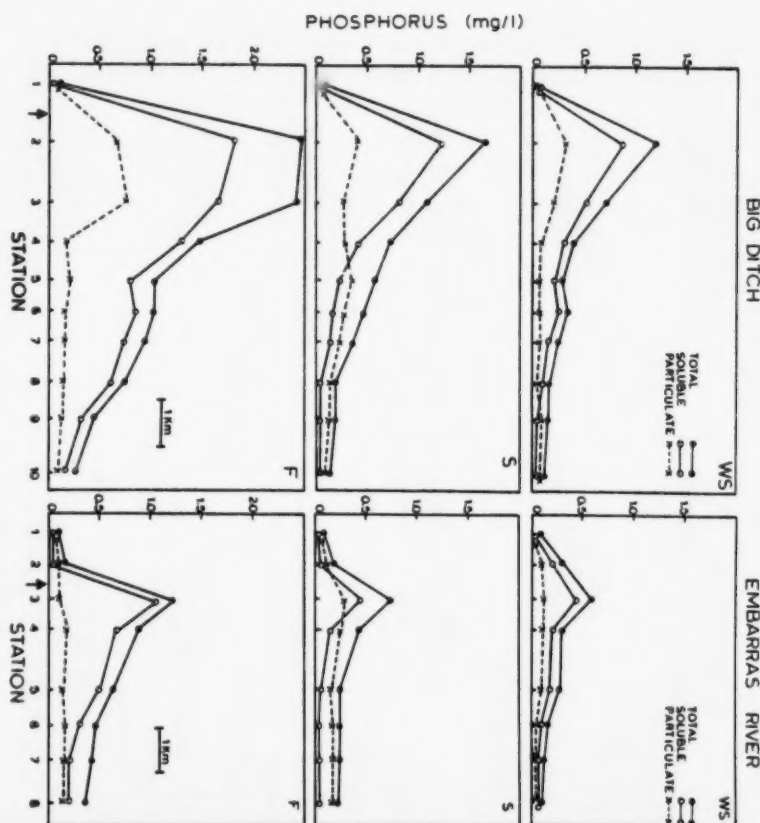


Figure 6. Seasonal Variation in Phosphorus Concentrations in Big Ditch and the Embarras River. WS - Winter-Spring; S - Summer; 1 - Fall. Position along abscissa proportional to distance from Station 1. Arrow indicates location of point input.

transport (Stall and Yang, 1972; Yang and Stall, 1974) with the theory of production and transport of organic material (Stall, et al., 1978; Cummins, 1974; Cummins, et al., 1972; Schlosser and Bachmann, 1976). To predict water quality during periods of surface runoff, erosion production from agricultural theory should be combined with the geomorphological concept of stream equilibrium and sediment transport (Schlosser and Karr, 1981).

When riparian vegetation is maintained in areas of intensive agriculture, suspended solids levels that are both constant and lower will result due to reduced instream organic production.

It would also improve water quality during surface runoff by enhancing sediment deposition in near stream areas and reducing the scour of stream banks (Schlosser and Karr, 1981). The importance of riparian vegetation to water quality in which occurrence in forest management (Manning, 1975; Benman and Lacey, 1979). It is essential that a similar near-agricultural perspective also be instituted in intensive agricultural watersheds.

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